Evaluation of an Improved Retrieval of OMI NO_2 Column Using Within Boundary Layer Aircraft Observations

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Introduction

Retrieval of NO_2 vertical column density from raw reflectance data observed from space depends on viewing geometry, terrain height, terrain reflectivity (albedo), and the NO_2 vertical profile shape. Current NO_2 column retrieval algorithms produced by the NASA Goddard Space Flight Center (GSFC) and the Netherlands Royal Meteorological Institute (KNMI) utilize terrain and profile shape databases with coarse spatial and temporal resolution (Table 1). There is some evidence that higher resolution albedo and surface pressure would improve the products (Schaub, 2007; Zhou, 2009). However, improved retrievals have not been the subject of intense scrutiny or broad comparisons to in situ observations. Here, we describe an OMI NO_2 retrieval based on high spatial and temporal resolution surface albedo, terrain pressure, and NO_2 vertical profile shape. We present a new approach, utilizing aircraft observations collected in the planetary boundary layer-as opposed to requiring complete profiles-for comparison with satellite observations and use these observations to evaluate our revised retrieval of tropospheric column NO_2.

Improved Retrieval of NO_2 Vertical Column Density

Previous work has shown that the uncertainty introduced into the retrieved column is on the order of ~10-30% each for current terrain and profile inputs (Boersma et al., 2004;Zhou et al., 2009;Hains et al., 2009). We have developed several new elements at improved spatial and temporal resolutions that are being tested and implemented in a revised retrieval (Table 1). We average each of the spatially-resolved datasets over the satellite pixel instead of using values at the center of the pixel so that the parameters are representative of the integrated pixel area. For a dataset over California, we observe differences of ±8% between our product and the standard product for terrain pressure, and differences ranging from -241% to 55% for terrain reflectivity. Monthly averaged WRF Chem profiles are used to eliminate the known seasonal bias in the Standard Product that exists from using yearly GEOS-Chem profiles (Lamsal et al., 2009). On average, our retrieval of tropospheric NO_2 column yields columns that are 29% smaller than those derived using the standard product.

	NASA OMI Standard Product	Dutch OMI DOMINO Product	This Work
Terrain Reflectivity	GOME derived, 1°× 1°, Monthly	GOME derived, 1°× 1°, Monthly	MODIS, 0.05°× 0.05°, 16 day
Terrain Pressure	SDP Toolkit 90 arcsec DEM map (pressure @ center of OMI footprint)	TM4 Model, 3°× 2° (pressure @ center of OMI footprint)	GLOBE 1km^2 topo. database avg'd to OMI
NO_2 Profile	GEOS-Chem 2°× 2.5°, Annually	TM4 Model, 3°× 2°, Daily	WRF-Chem 4km × 4km, Monthly

Table 1. Terrain reflectivity, terrain pressure, NO_2 profile shape utilized in each of the three satellite column NO_2 retrievals studied here.

Validation of OMI NO_2 using Boundary Layer Aircraft Observations

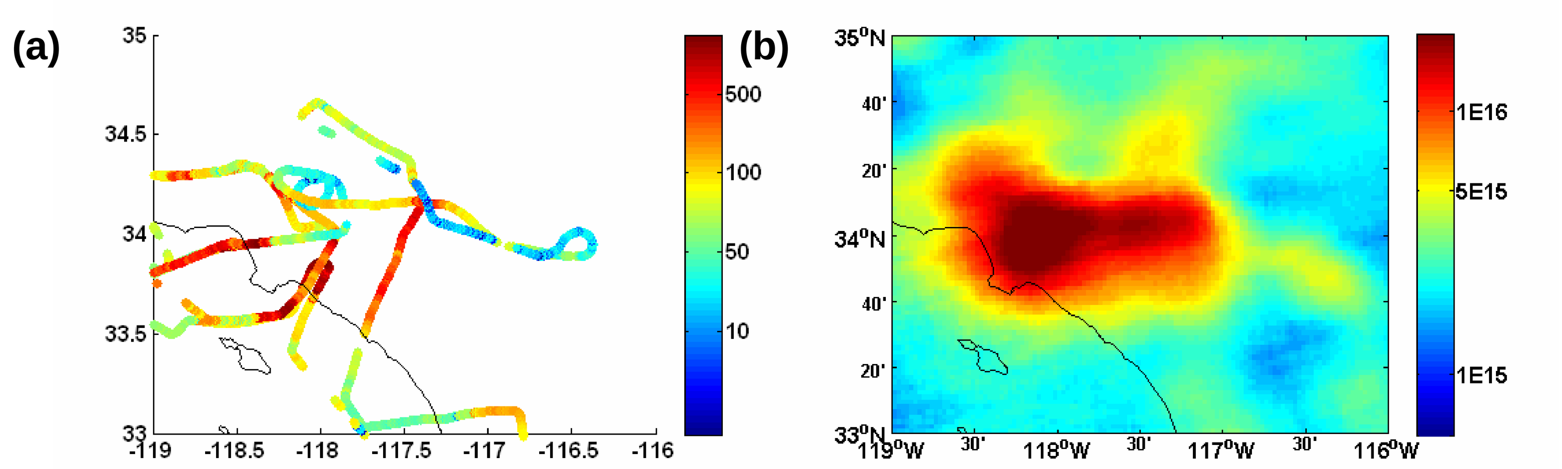

Figure 1. (a) Boundary layer NO_2 measured using UC-Berkeley's TD-LIF aboard NASA's DC-8 during ARCTAS-CA on June 18, 2008. (b) OMI tropospheric column NO_2 averaged for Jun-Aug 2008. The two figures show a clear correspondence between boundary layer aircraft measurements and satellite observations.

We estimate NO_2 vertical column densities from boundary layer aircraft observations using the Berkeley NO_2 instrument during the ARCTAS-CA campaign for comparison with satellite-observed NO_2 columns by first co-locating aircraft measurements with coincident satellite observations (Figure 2a). We include aircraft observations collected between 12:00pm and 3:00pm local time (OMI overpass @ 1:45pm) and require that at least 20 seconds of aircraft measurements were collected within the boundary layer and within the spatial extent of an OMI pixel. OMI pixels flagged during the retrieval process are excluded as well as pixels with a cloud fraction greater than 20%. The boundary layer (BL) height for each aircraft observation is defined by identifying large changes in aircraft measured NO_2 concentration, water vapor, and temperature with altitude to determine BL entrance and exit points. We assume that the BL height varies linearly between each entrance and exit as shown in Figure 2b. We further assume small horizontal variability of NO_2 in the free troposphere and that the boundary layer is well-mixed (Figure 2c). Aircraft measurements taken within a single satellite pixel are averaged and integrated to determine an inferred NO_2 vertical column density (Figure 2d). Results using this method are shown in Figure 3. Using traditional aircraft validation methods requiring complete spirals spanning the troposphere, only five comparisons would be possible, however, by using this method, we expand the number of comparisons to ninety-nine.

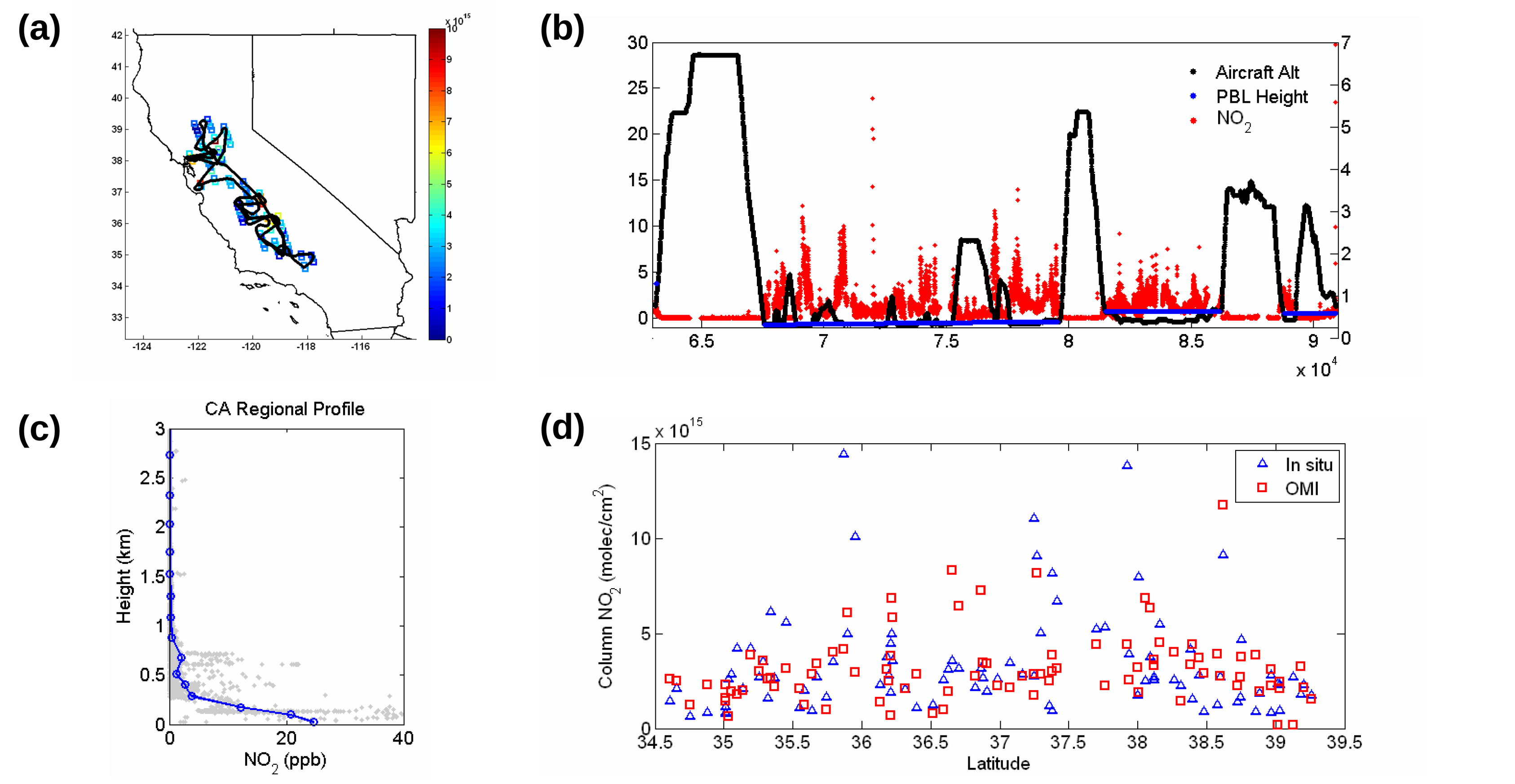

Figure 2. (a) The black line shows the flight path over CA of the DC-8 aircraft on June 20, 2008. Colored squares show the column concentration and location of the center of coincident OMI pixels. Red boxes show spirals available for traditional validation methods. (b) Pressure, NO_2 concentration, and inferred boundary layer height versus time for June 20th flight. (c) Vertical profile of NO_2 over California inferred from June 18th-24th flights. (d) In-situ derived column and OMI standard product (SP) columns on June 20th.

We compare columns estimated from the aircraft observations to the three OMI retrievals described in Table 1. We find dramatically improved correlation between our new retrieval and the in situ measurements (R^2 = 0.71) compared to the Standard Product (R^2 = 0.51) and DOMINO product (R^2 = 0.49). This suggests that a large contribution to the variance between in situ and space based observations arises from terrain and profile biases in the retrieval. Correlations found here are comparable to those determined using full spirals in Bucsela et al. (R^2 = 0.70) and Hains et al. (R^2 = 0.85).

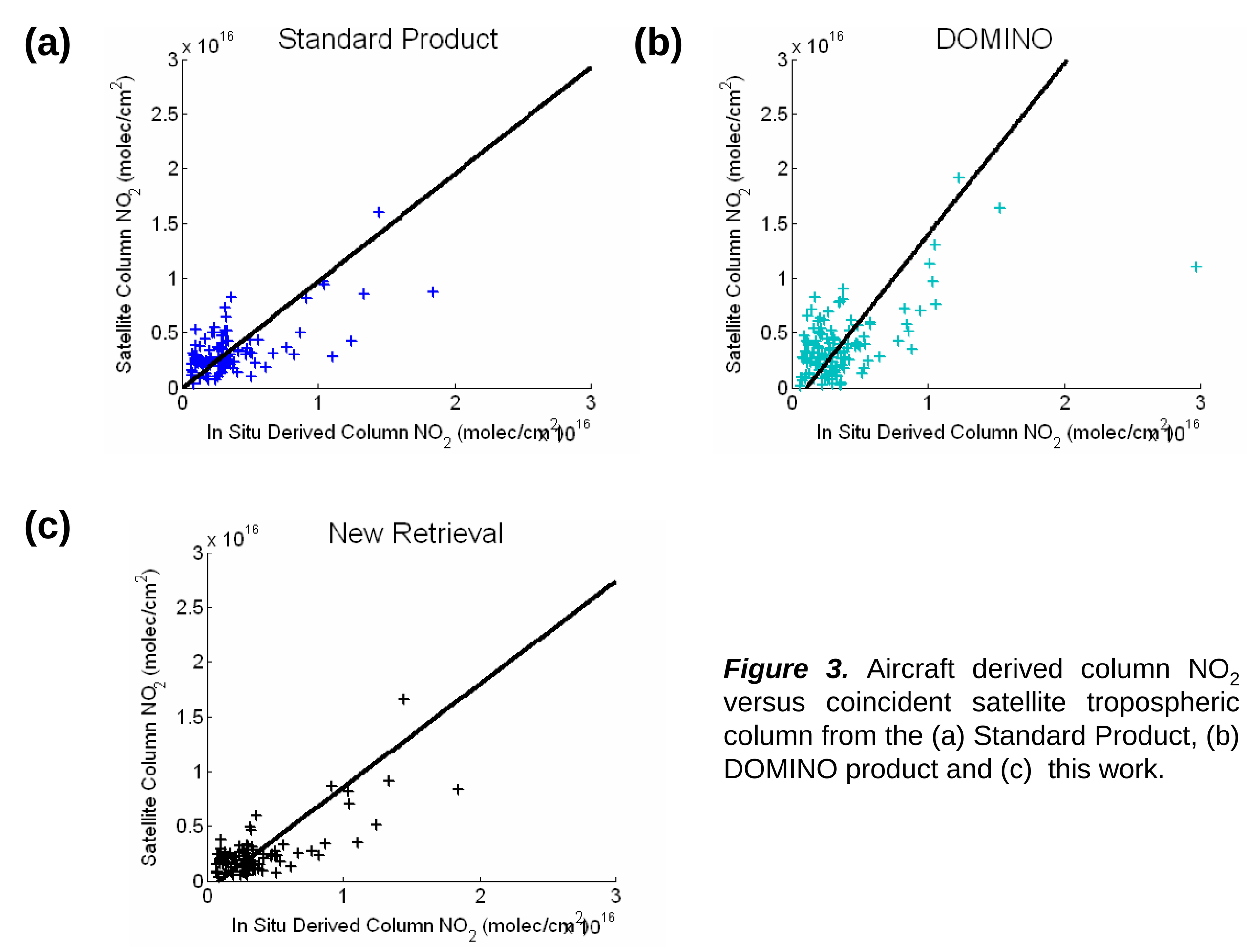

Figure 3. Aircraft derived column NO_2 versus coincident satellite tropospheric column from the (a) Standard Product, (b) DOMINO product and (c) this work.

Conclusions

Our retrieval using highly resolved terrain height, MODIS reflectivity, and WRF-Chem simulated NO_2 profile shapes, averaged to the OMI pixel size, shows improved correlation with aircraft measurements.

We have established a method for comparing boundary layer NO_2 measurements from aircraft with vertical column densities from space-based instruments. Our method vastly increases the size of the validation dataset by eliminating the need for full vertical profiles for each comparison.

We find correlations between in-situ derived and satellite observed NO_2 vertical column densities that are similar to those determined using full aircraft spirals, spanning the troposphere.

References

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Acknowledgements

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